General Aviation Runway Design Evaluation based on Aircraft Deviations from Runway Centerline

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***Abstract*— Accidents or Incidents where aircraft veer-off or overrun a runway, known as runway excursions, are among the most common abnormal events at general aviation airports. The design of a runway environment has direct effects on whether or not a given aircraft incurs a runway excursion as a result of an abnormal takeoff or landing. As runways continue to accommodate larger and faster aircraft, there is some question as to how current runway design standards protect against runway excursions. To assess this, this FAA supported research analyzes the deviation from centerline of aircraft operating on a general aviation runway. A configuration of LiDAR sensors and point cloud analysis was used to track aircraft using the runway for touch and go operations during calm wind conditions had minimal deviation, an average of less than 2 feet, from centerline. This may imply that the designed runway width specifications may be accurate if not generous. These preliminary results may offer the FAA an opportunity to revisit current design standards. Future research will analyze aircraft operations of various aircraft types under various atmospheric conditions in order to derive results that may benefit the FAA in future runway design considerations.**

Keywords: Runway design; runway excursion; LiDAR sensor; centerline deviation

I. Introduction

The movement of aircraft along runways during takeoff and landing operations is an important factor for airport planning and design. As the most important function of an airport is offering a safe and stable space for aircraft takeoff and landing, a runway has to be designed to maximize safety. To standardize and ensure safety, the Federal Aviation Administration (FAA) requires airports to design according to prescribed specifications not only the runway pavement itself, but also other additional buffer areas such as a runway shoulder, blast pad and other regulated invisible areas that restrict installation of fixed objects. [1]

Even though airport operators try to do their best to provide safe environment, as larger and fast aircraft use smaller runways, these design standards may come into question, particularly as these aircraft are now navigating to runways using advanced technologies. Despite the best design efforts to accommodate the rapid influx of new higher performance aircraft, particularly in the general aviation sector, aircraft accidents on runways still do occur. One of the most frequent accidents are runway excursions, defined as events where an aircraft's fuselage or wing deviates from the pavement on its designated runway during takeoff or landing operations. [2] Runway excursion accidents comprise a significant portion of total runway related accidents [3]. Specifically, runway excursions comprise more than 25% of the nation's total reported aviation accidents [4]. Approximately 42% of runway excursions caused fatalities [5].

The purpose of this research is to analyze the movement of aircraft along a runway's centerline during takeoff and landing operations to determine the overall accuracy of normal, and perhaps abnormal, operations. The result of these findings may help the Federal Aviation Administration determine the optimal design of runways to effectively mitigate runway excursions. For this research, a system of LiDAR based sensors was designed to capture the movement of aircraft, velocity of aircraft and a heading relative to the runway centerline along the aircraft movement track. Software was designed to model the captured data to evaluate the accuracy of these movements with respect to centerline tracking.

II. Background and Literature Review

A. Previous Studies

Nearly all previous studies investigating the potential deviations of aircraft moving along runway and taxiway centerlines have focused on large commercial airports, such as New York John. F. Kennedy International Airport (JFK) [6] and San Francisco International Airport (SFO) [7]. In these studies, the focus was primarily on the ability for airports to

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accommodate new large aircraft, such as the Airbus A-380 on existing airfields not originally designed for such large equipment. The primary design concern was within the taxiway environment, where relatively small deviations from centerline, particularly during turns, can result in aircraft landing gear deviating from the full strength pavement, or below-wing engines damaging airfield equipment such as lights and signage via either direct contact or by jet-blast. As a result of these studies, modifications to the FAA's Advisory Circular for Airport Design (FAA AC 150/5300-13A) were made to include refined taxiway design specifications [1]. Minimal attention in these previous studies have been paid to runway mitigation excursion. Furthermore, to date, there has been little literature that has focused on the movement of general aviation aircraft at smaller airports in the perspective of runway centerline deviation. As these smaller airports begin to accommodate larger and faster general aviation aircraft, any deviation from centerline upon landing or takeoff may result in a higher risk of runway excursions.

B. FAA and ICAO Runway Design Standards

For airports in the United States, the FAA provides runway dimensional standards based on an airport's "critical" or "design" aircraft. The critical/design aircraft is typically that aircraft that has the greatest approach speed and wingspan/tail height that regularly uses the runway. These aircraft specifications are used to categorize aircraft into several groups; Airplane Approach Category (AAC), based on the approach speed of the design aircraft and Airplane Design Group (ADG), based on the design aircraft's wingspan or tail height, whichever is larger. The combined indicator of an alphabet code of AAC and an ADG roman numeral is known as a Runway Design Code (RDC). [1] Internationally, the International Civil Aviation Organization (ICAO) recommends creates similar categorizations based on the design aircraft's "reference field length" and wingspan/main gear span. [8] Based on these aircraft characteristic groups, runway design specifications such as width, shoulder, blast pad or other runway safety areas are determined. For these design specifications, knowing how much aircraft deviate from the aimed runway centerline and factors that affect accuracy of aircraft control may help airports determine an optimal runway design specifications, particularly for general aviation aircraft using smaller airport runways.

C. National Runway Excursion Accident Statistics

There are several data sources that provide information regarding aviation accidents and incidents occurring in the United States. The Aviation Safety Reporting System (ASRS), supported by the National Aeronautics and Space Administration (NASA) [9] is a database of self-reported accidents, incidents, and other unusual events that occur during aircraft flights. Pilots are encouraged to report these events, in part to "self-declare" any incidents, which allow for the pilot to receive reduced punitive action, but also to provide the nation with data that may be used to analyze trends in unusual aviation activity. The aviation accident database and synopses of the National Transportation Safety Board (NTSB) is a database of all accidents and incidents that were formally investigated by the NTSB, including any events that resulted in substantial damage to aircraft or serious injury or fatalities to persons on the aircraft and/or in the surrounding area. [5] Data from these two sources data were analyzed for this study to determine the extent and cause of runway excursions. From the two data sources, the keyword of "runway excursion" was searched and excursion events were filtered. 168 reports in the ASRS database from 2006 to 2015 and 428 accidents in the NTSB database from 1991 to 2015 were determined to be runway excursion accidents. As each database contains detailed information of these accidents, such as airport, weather, pilot experience and causal factors, it was able to analyze the most common and frequent factors in excursions.

An analysis of the ASRS and NTSB "runway excursion" events, revealed that more than 80% of the aircraft involved in runway excursions were light aircraft having less than 12,500 lbs. of maximum takeoff weight, operating under FAR Part 91 "General Operating and Flight Rules", i.e. General Aviation. Approximately 78%, of the excursions were considered "veer-offs", that is, aircraft that leave the runway to the left or right side of the runway, while 17% were considered "over-runs", that is, those aircraft that over-ran the end of the runway. Approximately 70% of the excursions occurred during landing, and 21% during takeoff. Runway excursion events did not seem to occur any more often under reduced visibility, precipitation or otherwise contaminated runway surface conditions. Nearly 87% of excursions were on runways with length of less than 10,000ft. From this data it may be hypothesized that smaller general aviation airports are more prone to runway excursion accidents. As general aviation aircraft account for a significant percentage of the nation's total excursion events, it is clear that a research focused on general aviation airport runways is relevant.

III. Research Methodology

A. LiDAR System

The research goal was to as best as possible track the movement of aircraft longitudinally along a runway, and create an effective model for determining its movement with respect to centerline. To best capture these movements Toth, et. al. [10] developed a 3D profile LiDAR sensor system in conjunction with this research. LiDAR was chosen due to its low cost and high sampling rate. Among seven tested products, the VLP-16, produced by Velodyne, was selected to be used. This scanner offers a real-time view, 360 degrees of horizontal view, and 3D distance. The signal range reaches

100m and the accuracy is 3cm, which is sufficient to study a degree of diversion from runway centerline. Each sensor is small as a runway and taxiway light, may be placed on a frangible runway edge light base along a runway centerline in compliance with runway safety area standards. (Note: at the current stage of research, the system was installed near a runway that was temporarily closed to the public.). Fig. 1 illustrates the sensors mounted on runway light bases.

In this study, four sensors were used to improve acquisition of reflection. Four sensors were divided into two groups and each group was set on one lighting pillar with 0.5m of height. For the first group, both of the two sensors have horizontal axes. Sensors with horizontal axis has a narrow field of view and for this reason, to expand the scanning range, two sensors face different directions about 30 degrees between each sensor. The other group has different axes between each scanner; one scanner was mounted on the top of the pillar, having vertical axis and the other scanner's axis is perpendicular to the vertical axis sensor. Scanned image from horizontal rotation sensor is used for localization and vertical placement results help mapping and 3D model reconstruction.

Each LiDAR equipped pillar is also attached with GPS receivers to collect the high accuracy of time information which is critical for data calibration. Fig. 2 shows a deployed scanning system which consists of a sensor, interface box, GPS antenna, GPS receiver, power supply and computer.

Figure 1. LiDAR sensors mounted on a runway light base [10]

Figure 2. The single scanning system [10]

B. Aircraft point cloud collection and analysis

The data of scanned aircraft movements were collected from two different locations on the Ohio State University (OSU) Don Scott Airport. The first location was Taxiway A and various taxilanes on the OSU Flight education ramp where most of the aircraft maneuver in relatively slow speeds. The other data collection was carried on runway 9L/27R capturing landing and taking off aircraft with faster speeds in comparison to the taxiing aircraft. For the data collection, two sensor pillars were placed on the same edge of taxiway, taxilane and runway. Two pillars were separated in 40m distance between them. Fig. 3 shows the angle and range of four scanners based on the determined configuration.

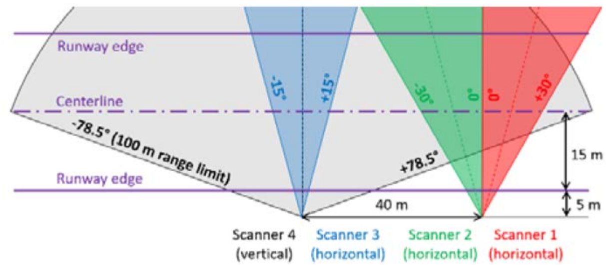

Figure 3. Scanning range based on the configuration of four sensors [10]

Data collected from the sensor system was processed to create point cloud images of moving aircraft, as illustrated in Fig. 4, depicting a high-wing single piston engine aircraft, specifically a Cessna 150.

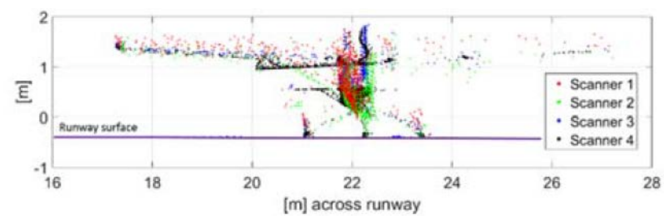

Figure 4. Refined and combined aircraft image from four scanners [10]

Fig. 5 illustrates the placement of point cloud data on a time vs. velocity and time vs. heading graph. In this example, the red line depicts the modeled change in velocity over time of a landing aircraft. The blue circles depict change in heading over time.

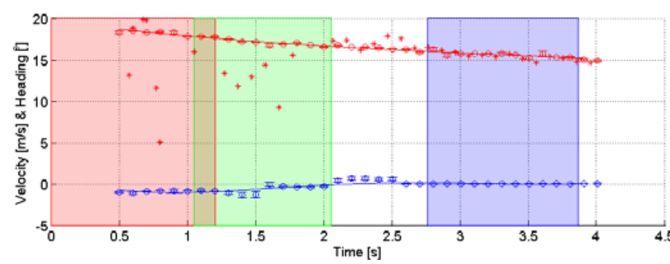

Figure 5. Comparison of estimated and actual velocities (red) and heading curves (blue) [10]

The blue line, which models the change of direction of the aircraft, illustrates that the nose traveled left and right side of centerline for the first 2.5 seconds of landing. Then, the track of airplane matches the runway centerline. The above graphs show that the algorithm fits well when the velocity of aircraft is relatively slow.

The Fig. 6 shows the track of landing Cessna on a satellite image map overlay. The red line is the calculated movement of the aircraft, which is close to the centerline. Based on this calculated route, the deviation of aircraft track from the runway centerline may be observed and quantified.

Figure 6. Track of landing aircraft [11]

IV. ANALYSIS OF DATA AND FUTURE RESEARCH

The reconstructed aircraft model from LiDAR sensors can be used for the estimation of aircraft heading and velocity. The refined point cloud of airframe gives us a touchdown point and landing roll trajectory on a runway surface with high accuracy. For example, in the case of the Fig. 5 and Fig. 6, at the touchdown point, the velocity of aircraft was relatively fast. The aircraft landed approximately 0.1m right of centerline and maintained the right-hand side heading until it reached at 0.3m. The pilot tried to correct the direction, but overcorrected and strayed toward left side of the centerline. After the track was deviated about 0.15m to left, the pilot properly adjusted the aircraft's heading and tracked the remainder of its ground roll on the centerline. The aircraft oscillated between each direction and for approximately 2.5 seconds, then direction was settled and the aircraft maintained a straight profile along centerline prior to its touch-and-go departure.

This initial research found that the developed sensor system could successfully capture the aircraft body and paths. During the initial field tests, less than 20 aircraft movements along the taxiways and 25 touch-and-go operations were observed and analyzed. Most of the targets were Cessna 150 and Cessna 172 single engine piston aircraft. The winds were calm, the weather was clear allowing for normal touch and go operations. During these operations, minimal deviations from centerline were observed, on the order of less than 1.0 meters of deviation in nearly all cases.

Clearly, there exists a wide variety sizes and speeds of aircraft and operation types at general aviation airports. Furthermore, ambient conditions, particularly winds and visibility, can certainly affect the accuracy of aircraft movements along centerline. As such, it is necessary to collect a much large set of observations of various sizes and speeds of aircraft in diverse environment. This larger scale data collection exercise will be the next phase of this research.

After sufficient data is collected, trajectory lines from the variety of observed aircraft will be plotted on a satellite image map similar to the illustration in Fig. 6. Such drawings will show the average and deviations of landing and takeoff roll trajectories. In addition, statistical analysis of these deviations will be performed. It is hope that this more extensive analysis will provide findings that be considered for the determination of runway component specifications. In addition, this analysis, combined with other runway veer-off excursion causal factor analysis, from published ASRS and NTSB data, may offer a more precise method of understanding the cause of runway excursions, which may further guide the aviation community in mitigating these potentially harmful events.

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